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APPLICATION OF SATELLITE AND AIRBORNE GEOPHYSICAL IMAGERY IN THE SEARCH FOR MASSIVE SULPHIDE DEPOSITS, HEATH STEELE AREA, NEW BRUNSWICK, CANADA

by

J.G. Torrance and M. Lodin

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NEW BRUNSWICK DEPARTMENT
OF NATURAL RESOURCES & ENERGY
MINERALS AND ENERGY DIVISION

CANADA - NEW BRUNSWICK M.D.A.
HEATH STEELE MINES PROJECT

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APPLICATION OF SATELLITE AND AIRBORNE GEOPHYSICAL IMAGERY IN THE SEARCH FOR MASSIVE SULPHIDE DEPOSITS, HEATH STEELE AREA, NEW BRUNSWICK, CANADA

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ABSTRACT

Owing to the paucity of rock exposure and the structural complexities in the Heath Steele Mines area of the Bathurst mining camp, geologic interpretation of the region has been inhibited. Only through very detailed geologic mapping has an appreciation for the structure controlling the spatial distribution of sulphide deposits been gained. For this reason it was decided that remote sensing techniques should be employed to add further information to the geological database.

Multi-date LANDSAT MSS and LANDSAT TM satellite digital imagery was acquired and analysed. Computer search for multi-spectral characteristics (signatures) similar to those of known gossan occurrences was conducted using discrete pixel and aerial search parameters. An integrated approach combining both digital satellite imagery and interpolated airborne geophysical raster data was employed.

A fully annotated, continuous tone, TM base map was plotted on paper at 1:50 000 scale using a Calcomp 5835 plotter. Binary colour image TM signature search plots were produced on acetate at the same scale so that they could be overlaid on the basemap. Aerially significant gossan targets were found to the west and north of the Heath Steele mine site.

The processing of spatially registered digital image data from a variety of sources allows for rapid and varied integration of the available information. This database can be employed in the search for massive sulphide deposits in the volcanic terrain of the Bathurst camp in areas of little or no rock exposure. Ease of correlation with geophysical data affords a here-to-fore unavailable tool for the exploration geologist.

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1. INTRODUCTION

1.1 Geologic Setting

The Heath Steele area is situated 60 km northwest of Newcastle, New Brunswick (Figure 1). There are eight geologically significant massive sulphide deposits located on Mining Lease #238 belonging to Heath Steele Mines Limited. Most of the geologic ore reserves, estimated at 25 000 000 tonnes of Zn-Pb-Cu-Ag ore (Davies et al. 1983), are contained within only two ore zones.

The sulphide deposits lie conformably within a sequence of multi-folded, faulted, and weakly metamorphosed felsic volcanic, volcaniclastic, and metasedimentary rock units of the Cambro-Ordovician Tetagouche Group. This group is composed of a bimodal suite of felsic and mafic volcanic and associated pyroclastic rocks in addition to phyllitic metasediments (Skinner 1974). Together these units form an irregular arcuate volcanic complex in northern New Brunswick that is host to several other stratabound massive sulphide deposits.

The area is characterized by poor rock exposure and complex geological structure. For this reason, it was decided to employ digital satellite imagery as an additional mapping tool. Multi-date LANDSAT MSS[3] (4 spectral bands) and LANDSAT TM[4] (7 spectral bands) were combined with interpolated airborne vertical gradient magnetic data.

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[3] - Multi Spectral Scanner

[4] - Thematic Mapper

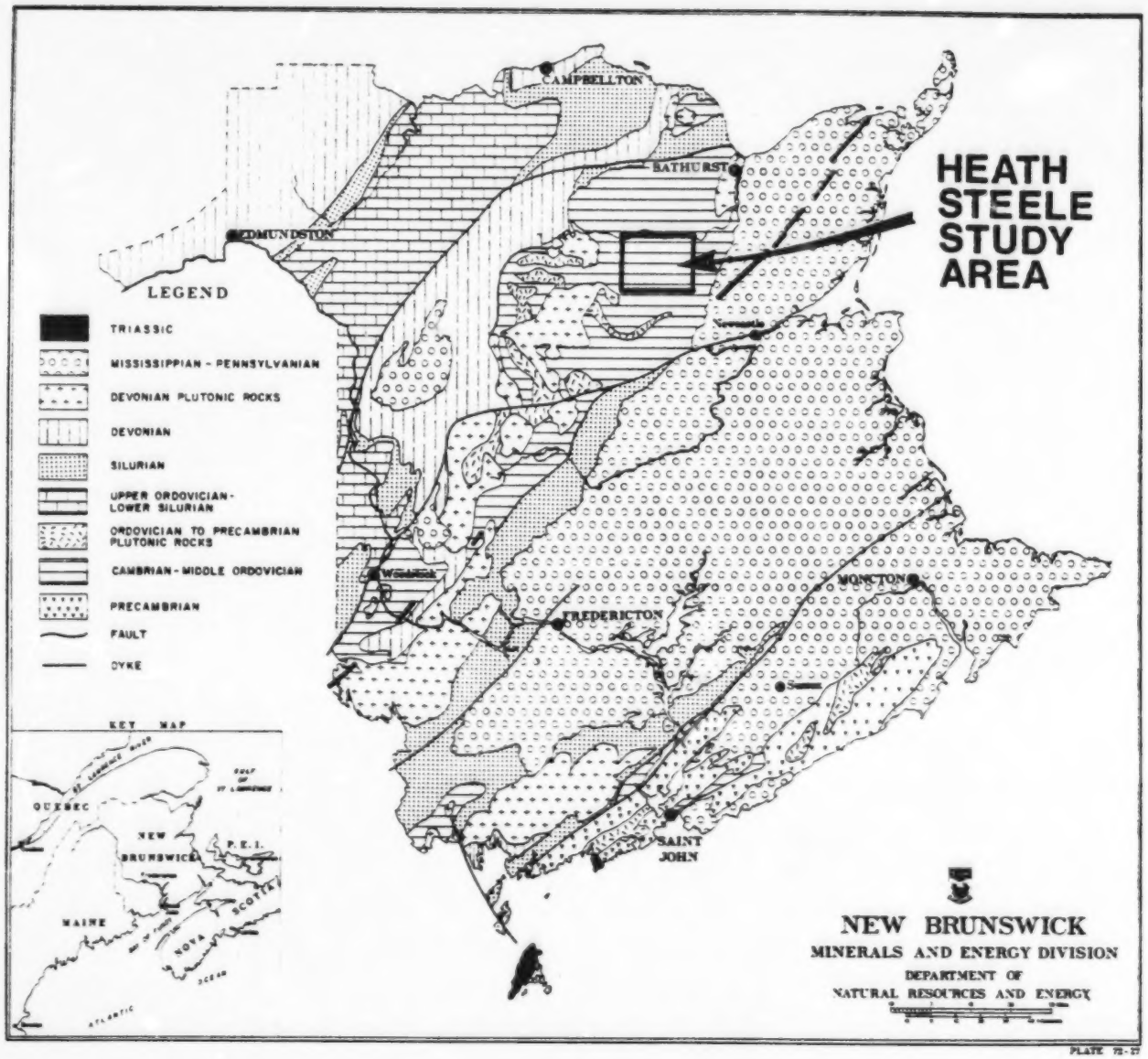

Figure 1. Heath Steele location map.

1.2 Geobotany

In New Brunswick extensive forest cover hinders the determination of relations between surface and subsurface phenomena. However, geobotany should not be overlooked as a suitable means of interpretation of remote sensing data.

Geobotany is generally defined as the visual survey of vegetation in order to define geological differences in landscape (Raines and Canney 1980). It is very difficult to describe all factors of the bedrock/soil/vegetation relationship due to the variety of local conditions. The main assumption is that there is a direct correlation between the soil and the underlying bedrock. This relationship can be of a chemical (interchange of micronutrients, moisture, etc.) or morphological (slope effects, differential erosion) nature. Convincing results are described in the outlining of limestones, shallow ultramafic bedrock, and sulphide accumulations (Hawkes & Webb 1976).

Spectral reflectance from green vegetation is low in the blue and red region of the electromagnetic spectrum, higher in the green region, and highest in the near infrared region (Figure 2). This reflectance rapidly diminishes with the ill health of the plant as caused by factors such as anomalous accumulations of metals.

Plants respond to the accumulations of metallic minerals by undergoing physiological and morphological changes that result in alteration of their outward appearance. This can be detected in the more sensitive infrared region as the subtle reflectance changes depend on the leaf cellular structure, water content, and change in plant pigment.

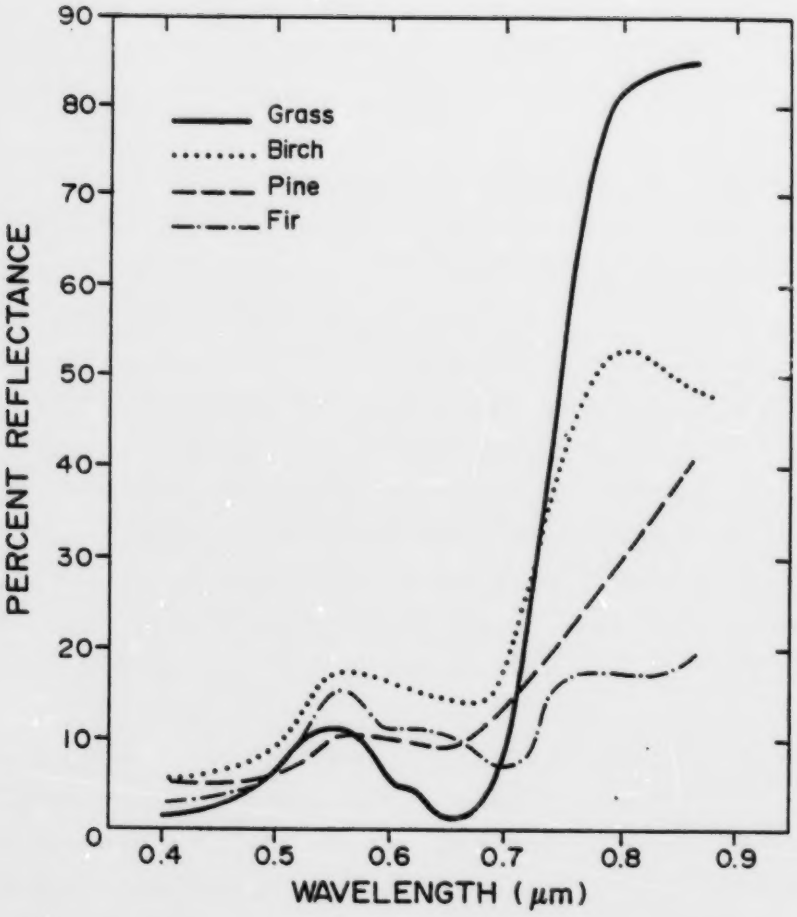

Figure 2. Detectability of plant species in the infrared region of the electromagnetic spectrum. Note: The lower limit of near infrared is at 0.7 μm. After Hawkes and Webb, 1976.

1.3 Satellite Characteristics

Digital data from the LANDSAT satellites obtained by the MSS and TM sensors were used in this project. Comparison of the spectral bands of both of these satellite/sensor configurations is made in Table 1.

Although the more advanced LANDSAT TM is based on the technology of the earlier MSS, it achieves sharper image

resolution, colour separation, and greater in-flight geometric and radiometric accuracy for seven spectral bands simultaneously.

TABLE 1.

Comparison of LANDSAT-MSS and LANDSAT-TM Satellite Bands and Resolutions

Remote Sensing Data Specification			
Satellite Name	Spectral Band #	Wavelength Range (μm)	Resolution (m)
LANDSAT MSS	4	0.50 - 0.60	79.0
	5	0.60 - 0.70	79.0
	6	0.70 - 0.80	79.0
	7	0.80 - 1.10	79.0
LANDSAT TM	1	0.45 - 0.52	30.0
	2	0.52 - 0.60	30.0
	3	0.63 - 0.69	30.0
	4	0.76 - 0.90	30.0
	5	1.55 - 1.75	30.0
	6	10.40 -12.50	120.0
	7	2.08 - 2.35	30.0

Three of the seven TM bands approximate those of the MSS, but the narrower green and red bands improve sensitivity to spectral changes in vegetation reflectance. The TM infrared band 4 has a narrower band-width than that of the MSS band 7 thereby increasing sensitivity to plant growth. The significant additions to the TM are the blue (band 1), mid-infrared (band 7), and thermal (band 6).

2. BASIC CONCEPTS

2.1 Remote Sensing

Remote sensing is defined as a visual and numerical communication system, which employs sensors not in contact with points or areas of interest. It acquires and processes data in different ranges of the electromagnetic spectrum. Remote sensing detectors permit detection of previously unmapped targets as well as physical and chemical phenomena in the earth's environment.

Data acquired by these means can be converted into information by visual inspection or analysis by optical or computer systems. Techniques of remote sensing address the identification and classification of earth phenomena by detecting spatial, spectral, and temporal variations of targets, scenes, and events.

The electromagnetic spectrum is separated into eight major divisions from γ-rays through to very low frequency pulse emissions. Satellite and airborne sensors typically operate in the ultraviolet, visible, infrared, thermal, and microwave portions of the electromagnetic spectrum (Figure 3). Depending on the detector used, the quantity measured may be energy, power, or intensity at specified wavelengths or frequencies.

One of the principal advantages of remote sensing imagery is that it may be obtained simultaneously from several portions of the spectrum that are not detectable by the human eye.

Since remote sensing of the earth's surface is, by definition, done at a distance, it is inevitable that sensed radiation has had to pass through the atmosphere. The path

distance and atmospheric conditions are variable. Portions of the electromagnetic spectrum that are relatively unaffected by atmospheric reflection, absorption, or scattering are termed "atmospheric windows" (Figure 3).

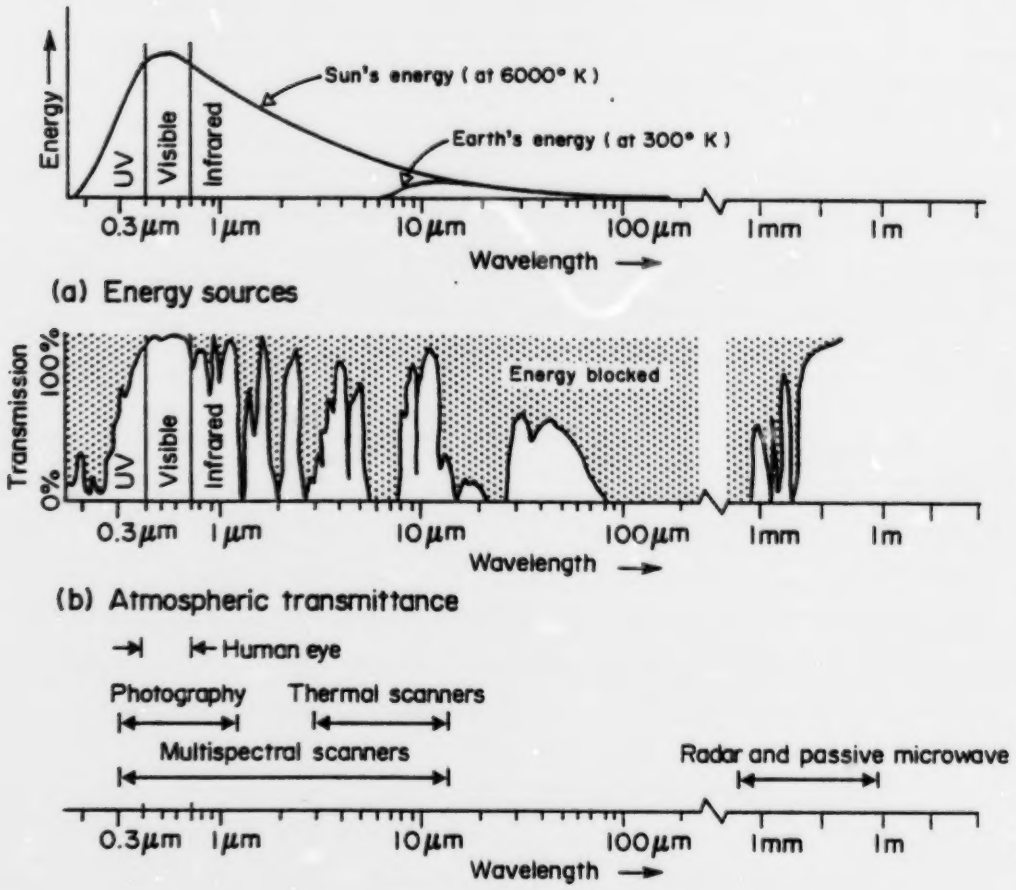

Figure 3. Spectral characteristics of energy sources, atmospheric effects, and sensors. (After Lillesand and Kiefer 1979).

2.2 Data Integration

Various types of spatial data are collected in a wide range of disciplines. Usually, these data are considered individually or the occurrence of a specific feature is "checked" on the available data types. However, maximum utilization of the available data sources is achieved only when they are considered collectively. The term "synergism", or the "Synergistic" approach is described by Goebel et al. (1979), as a "Combination of two or more data sources aimed at the recognition of spatial characteristics which are not readily identifiable on any single data type".

Computer-aided digital data acquisition and processing increases the ease of retrieval, integration, and analytical power of spatial data analysis. Geographic Information Systems can be employed as part of the process of multi-source data investigation.

A Geographic Information System is a computer based system that allows input, analysis, and display of spatial information. Spatial information consists of both graphical (geometrical) and attribute information. Graphical information refers to the shape, size, and length of features as well as their spatial relationships. Attributes, on the other hand, describe the properties of such features.

Various data types can now be registered to a common grid and operated upon simultaneously. Regardless of the scale, size, projection, and resolution, various types of data can be spatially related (overlaid) and processed both individually and collectively. Overlays can contain any combination of original or processed data and can be interpreted both visually and statistically.

2.3 Data Selection

The main considerations in selecting appropriate data sets for integration are: (a) that the data sets have compatible resolutions; (b) data suitability, i.e., does one data set complement the other; and (c) data density, i.e., are point data of sufficient density for integration with raster imagery.

3. METHODOLOGY

3.1 Digital Imagery

A digital image is a numerical representation of a sampled field. The field is represented by the radiance of a given scene viewed in some region of the electromagnetic spectrum. The digital image is generated by sampling and measuring the local field strength at points arranged in a rectilinear pattern. Field strength of the spectral range is then encoded as an integer (pixel value). The digital image is represented as a discrete set of values, not a continuous tone photographic image.

Digital images can be readily manipulated by computer systems to prepare a more effective display of image data. Extraction of information by analytical procedures can yield results that may or may not be apparent by simple inspection.

The analytical techniques described by Gillespie (1980), can be separated into the following broad catagories:

Geometric manipulation - the basic spatial relationships between individual features is modified.

Radiometric manipulation - the brightness encoding scheme of the digital data is modified.

Spatial filtering - the spatial domain of the Fourier spectrum is modified.

Multispectral manipulation - the spectral content of images is modified to create new data formats including Thematic maps which depict computer enhancements of features in a given scene.

The significance of digital image processing becomes apparent given, that the human eye can distinguish approximately 12 grey tones as opposed to 256 used by the computer. Displaying images as colour composites further increases the tonal range to approximately 1.5 million possible colour-tone combinations. Hence, the computer is capable of detecting subtle tonal gradients and patterns in the imagery that would go undetected by the human eye.

3.2 Geometric Corrections

All analysed data were registered to the UTM grid. The accuracy of correction was evaluated for every Ground Control Point (GCP) on the basis of line and pixel residuals and actual pixel shift. The residual coefficients represent the "fit" of each GCP to the Polynomial Transform Function (PTF). The pixel shift is a measure of the proximity calculated by PTF for each GCP to its actual position on the image. For the imagery used over the Heath Steele area, residuals did not exceed 26.28 metres, and the pixel shift was not greater than two pixels for any given GCP.

3.3 Tonal Enhancements

Limited overburden (≤10 m of glacial till) in the Heath Steele area allows the assumption of a relationship between bedrock composition and vegetation variation. Such a variation is detected with greater sensitivity on the LANDSAT infrared spectral bands.

Biomass index, band normalization, and principal component analysis were found to be applicable. Results of arithmetic enhancements were used individually as input into principal component generation.

Principal component analysis produces an image that emphasizes radiometric variations within a selected part of the scene at the expense of spectrally diverse areas. Subtle differences in patterns are highlighted within areas of interest. In principle, images containing initially similar information (correlated images) are transformed into a different coordinate system where the degree of similarity between them is minimized.

Areas covered by water (lakes, streams, swamps) and clearcut regions were excluded from the analysis. The exclusion of these zones of extreme reflectance brings the shape of the original frequency histogram closer to that of a Gaussian distribution. This important step compensates for the bias of initially non-normal data distribution when entered into eigenvalue calculation. In the case of non-normal distributions, entered mean and standard deviation are not representative quantities of the data set.

3.4 Signature Search

A computer search for spectral and geophysical signatures of known gossan occurrences was conducted using two different techniques. These are referred to below as search by discrete pixel and search by area. Each technique uses test areas defined by a known rock outcrop in a naturally vegetated environment (clearcuts, forest burns, and otherwise disturbed regions were excluded from the search).

The northwestern part of the 'A-C-D' zone and the eastern segment of the 'E' zone at Heath Steele (Plate 88-44)

were used as the test areas for the signature searches. While the 'C' zone has what is considered to be a true gossan, the massive sulphides of the 'E' zone come to surface and are highly oxidized. The combination of these two subtly differing modes of expression broadens the bounds of the statistical correlation.

Computer search by discrete pixel examined two images simultaneously by assigning a colour to all pixels having intensity values identical to the test areas. All original bands and best enhancements were tested as input in this procedure.

Computer search by area enabled the examination of up to sixteen different images at the same time. These test areas were specified by mean and intensity value tolerance (multiple of standard deviation).

4. GEOPHYSICAL DATA PROCESSING

4.1 Acquisition

Contour maps of both vertical gradiometer and total field magnetic airborne data were obtained from the Geological Survey of Canada. These data were digitally registered to the UTM grid using a MicroVax-based CARIS[5] workstation. Digitized vector data files were reformatted and interpolated. Various interpolation routines were tested with greatest success obtained using symmetric positive-definite matrix inversion and second degree polynomial. The resultant data files were converted into raster form readable by a PDP/11-based DIPIX Aries II Image Analysis System.

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[5] - Computer Aided Resource Information System

4.2 Display and Scaling

Interpolated data files were rescaled to a positive integer form with total range magnitudes spanning 0 to 255 grey tones. The overlay of both continuous tone and directionally illuminated geophysical data with original and enhanced satellite imagery enabled the correlation with image patterns (Fig. 4).

Figure 4. Image of the Heath Steele area (H = mill complex). Interpolated vertical gradient magnetic data are superimposed on a TM band 2 image. High positive magnetic gradients are white, negative gradients are black.

4.3 Integration

The discrete pixel and aerial searches incorporated both satellite and geophysical image data. Statistical tolerances (multiples of the standard deviation from the mean of the gossan test areas) were input into the system to constrain the range of pixel values that would be "matched" during the signature search procedure.

5. RESULTS

5.1 Technical

Of all the combinations of LANDSAT bands tested in the discrete pixel signature search, the best results (tonal clustering) were obtained using either: (a) normalized band 6 (thermal) and a low-pass filter of the interpolated vertical gradient magnetometer; or (b) first principal component and a low-pass filter of the interpolated vertical gradient magnetometer.

The best results for the aerial signature search were obtained by analysing the following band combinations simultaneously: Biomass indices for bands 2, 5, and 7; all seven original bands excluding extremes caused by water bodies and clearcuts; and both the original and low-pass filtered interpolated vertical gradient magnetometer data.

For aerial signature searches, the best results were acquired using statistical tolerances of $\frac{1}{2}\sigma$ and 1σ. The "concentrated" nature of the individual tonal clusters and low background "noise" in the gossan theme file image (Figures 5 & 6) attests to the statistical uniqueness of the integrated approach. Areas of overlap between the $\frac{1}{2}\sigma$ and 1σ tonal clusters represent high-probability gossan targets.

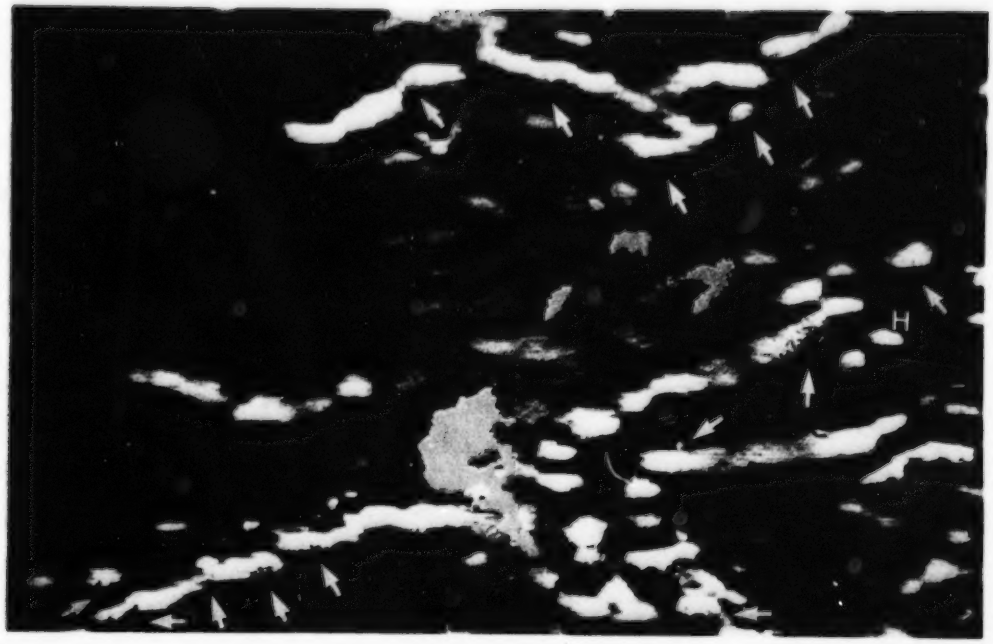

Figure 5. Low-pass filtered vertical gradient magnetic image (grey tone background) with signature search pixel clusters superimposed (indicated by the white arrows). The vertical gradient magnetic image has been artificially illuminated from the north. H = Heath Steele Mill complex.

5.2 Geological

The results of both the discrete pixel and aerial gossan signature searches are displayed on Plate 88-44 (in map pocket). This map is a compilation of information displayed on an original false-coloured LANDSAT TM base map and a

binary colour acetate overlay[6], both of the Heath Steele area.

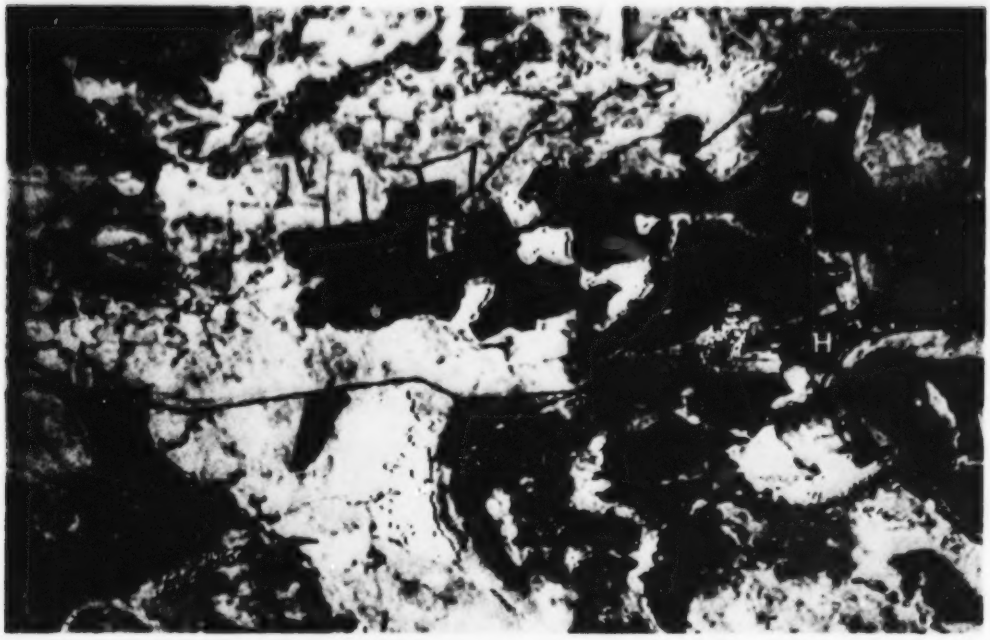

Figure 6. Gossan signature search pixel clusters (grey dots) superimposed on a TM band 2 image of the Heath Steele area for geographic reference.

Several tonal clusters are evident on Plate 88-44. The clusters marked 'ACD', 'B', 'E', and 'F' correspond to sulphide zones of the same name on the Heath Steele Mines Limited lease.

The tonal cluster expression of the 'B' zone is weak (discrete pixel correlation only) in comparison to that of

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6 - Copies of both the basemap and the acetate overlay are available from GEODAT Information Services Ltd., Fredericton, NB.

the 'A-C-D' zone. This observation may seem somewhat surprising since the 'B' zone has the greatest tonnage of all the sulphide zones at Heath Steele. This apparent contradiction is a result of the large amount of metallic debris and other waste on surface that masks the natural spectral response.

Other clusters located on Plate 88-44 correspond to areas of potential sulphide accumulation, with those clusters showing correlation of both the discrete and aerial search results having greater probability of being gossan (numbered 1 to 24). Alignment of many of these clusters (i.e., clusters 2, 3, and 4) in a ENE-WSW direction corresponds to the general strike of the volcanic rock units in this region and with the stratabound nature of the sulphide deposits in the Heath Steele area.

In the area 8 - 10 km west-southwest of the Heath Steele mill are three sizeable tonal clusters (2, 3, and 4) each having a 500 - 800 m strike length. A smaller cluster (#1) of 100 - 200 m strike length is located just to the north of #2. These clusters are aligned parallel to the dominant strike direction of the metasedimentary and felsic rock units in the area, and appear to lie at or near the contact of a thin quartz-chlorite-schist layer which is bounded on its north side by a multi-layered sequence of felsic rocks. This sequence is similar to that found at the 'A-C-D', 'B', and 'E' zones and may represent a folded or faulted extension of the Heath Steele mine horizon to the west.

As a result of the steeply dipping nature of the lithologic units in this area, clusters 2, 3, and 4 could have significant down-dip extensions and may represent sulphide accumulations comparable in size to that of the Heath Steele 'B' zone.

Other reasonably sized clusters (≥200m strike length) can be found to the north of Heath Steele in the Roger Lake area (Plate 88-44). A northeast-southwest alignment of these clusters in two subparallel trends is apparent. One trend passes to the north of Roger Lake (clusters 12, 13, 14) while the other (clusters 18, 19, 20, 21, 22) starts 1 km to the north of M^{c}Cormack Lake and passes to the southeast of Roger Lake. The southernmost trend could possibly represent an eastern extension of the sulphide bearing cherty-argillites of the Stratmat sequence.

The main mineralized zones at the Stratmat deposit were not detected by either the discrete pixel or aerial search techniques. This can be attributed to the fact that the majority of the Stratmat sulphide bodies lie beneath clearcut areas. In addition, the general absence of a gossan at Stratmat would result in a surficial spectral response sufficiently different so as to hinder successful search.

Within the Heath Steele Mines Limited Lease there is little indication of the near-surface presence of any sulphide accumulations between the 'A-C-D', 'E', 'B', and 'B5' mineralized zones. This fact is not surprising given the number of drill holes and geophysical surveys that have been conducted in this area over the past thirty years.

There is no indication of any near-surface sulphide concentrations on the favourable mine horizon (Plate 88-44) to the west of the 'ACD' zone, even where this horizon is tightly folded about a northwest-trending F2 hinge just to the east of North Little River Lake. However, there is indication of mineralization (clusters 5 & 6) on the Mowat horizon (Plate 88-44) which is folded about the same F2 axis but located to the southeast of the mine horizon. The Mowat horizon may represent: (a) a chronologically different

mineralizing event in the volcanic pile; or (b) the mine horizon repeated to the east by F1 folding (Plate 88-44). In either case gossan-like spectral responses within the Mowat horizon are found on the southern limb and in the nose of the F2 fold. It is not known whether the gossan clusters extend toward the northeast on the northern limb of this fold because a clearcut masks the "natural" spectral response in this area.

Just to the east of the Heath Steele Mining Lease is a chain of tonal clusters aligned in a east-northeast direction. Only one cluster (#10) shows correlation between the discrete pixel and aerial search results. This group of clusters occur on what could possibly be the eastern extension of the mine horizon. Surface geological and geophysical investigations in this area indicate that, at least in plan view, the mine horizon does not extend off the Heath Steele property to the east but instead is folded back on itself to the west. These clusters may therefore represent either an extension of the 'B5' zone sulphide horizon folded in the third dimension about a subhorizontal (F3?) axis, or a separate lens of sulphide bearing quartz-chlorite-schist.

Located 1 km to the south of cluster 10 lies cluster 9. This area is characterized by highly silicic, massive, fragmental, and schistose felsic volcanic rocks of homogeneous composition that are referred to as "acid volcanics" by the mine geologists. While this rock type is generally thought to be barren of sulphides, surface mapping and trenching have found sizeable layers of pyrite, manganese, and iron oxide rich rock. A large enough concentration of these materials in the otherwise monotonous sequence of acid volcanic rock could account for the presence of cluster 9 in this location.

Clusters 7 and 8 are located near the southern edge of the Heath Steele Mining Lease and lie in proximity to the Island Lake sulphide occurrence. This area is characterized by interleaved layers of quartz-feldspar-metaporphyry, meta-diabase, and a lesser amount of quartz-chlorite-schist. Mineralization is associated with the lenses of quartz-chlorite-schist and tends to occur at the contacts between this unit and the quartz-feldspar-metaporphyry. To the south of cluster 8 is the fault-bounded contact with metabasalts which are thought to form the base of the bimodal suite of volcanic rocks of the Tetagouche Group. No mineralization is found in this region.

Several smaller clusters of aerial extent similar to that of the Heath Steele 'E' zone are evident on Plate 88-44. Many of these clusters (i.e. 11, 15, 16, 17, 22, 23, and 24) are in areas in which the geology is unfamiliar to the authors, although all are located within the Ordovician felsic suite of rocks found in this area. It is worth noting that cluster 24 is located near the Consolidated Morrison sulphide occurrence and is elongated in a direction subparallel to that of the general strike of the lithologic units in this region.

6. CONCLUSIONS

The integration of satellite and geophysical image data can serve as a foundation for a multi-source spatially referenced digital database. Costly operations used in geological studies (i.e. drilling, geochemical, and geophysical surveys) are designed on the basis of a relatively thin layer of information (geological maps and sections). Benefits to be gained from the database operation include reduced cost of data acquisition, continuous

availability of coverage, ease of data retrieval, update, and increased analytical capability.

The base maps produced from such a database can serve as a spatial reference and display recent land use/land cover conditions (eg., clearcuts, logging roads etc). Correlating these features with enhanced image data allows for the discrimination of cultural and geological phenomena.

Rock-type signature cluster maps generated from the multi-source database can be successfully used to delineate target areas for ground verification of anomalous sulphide accumulation. While all tonal clusters indicated on Plate 88-44 may represent anomalous accumulations of sulphides, those numbered (1-24) display correlation of both search techniques and are therefore the best gossan targets.

Based upon our knowledge of the lithology, structure, and distribution of existing sulphide bodies in the Heath Steele area, the clusters that merit the greatest attention are: (a) those located to the west of North Little River Lake (1, 2, 3, and 4) which may lie on the western extension of the mine horizon; (b) clusters 18 & 19 situated on what may be the same stratigraphic horizon as the Stratmat deposits; (c) clusters 5 & 6 and the northeastern extension of the Mowat horizon; and (d) cluster 24 which has a 1 km strike extent and orientation consistent with that found at the nearby Consolidated Morrison sulphide occurrence. This list does not preclude the potential of the other numbered tonal clusters in the Heath Steele area, but is in part a function of our knowledge about the geology further from the Heath Steele Mines Limited lease.

7. ACKNOWLEDGEMENTS

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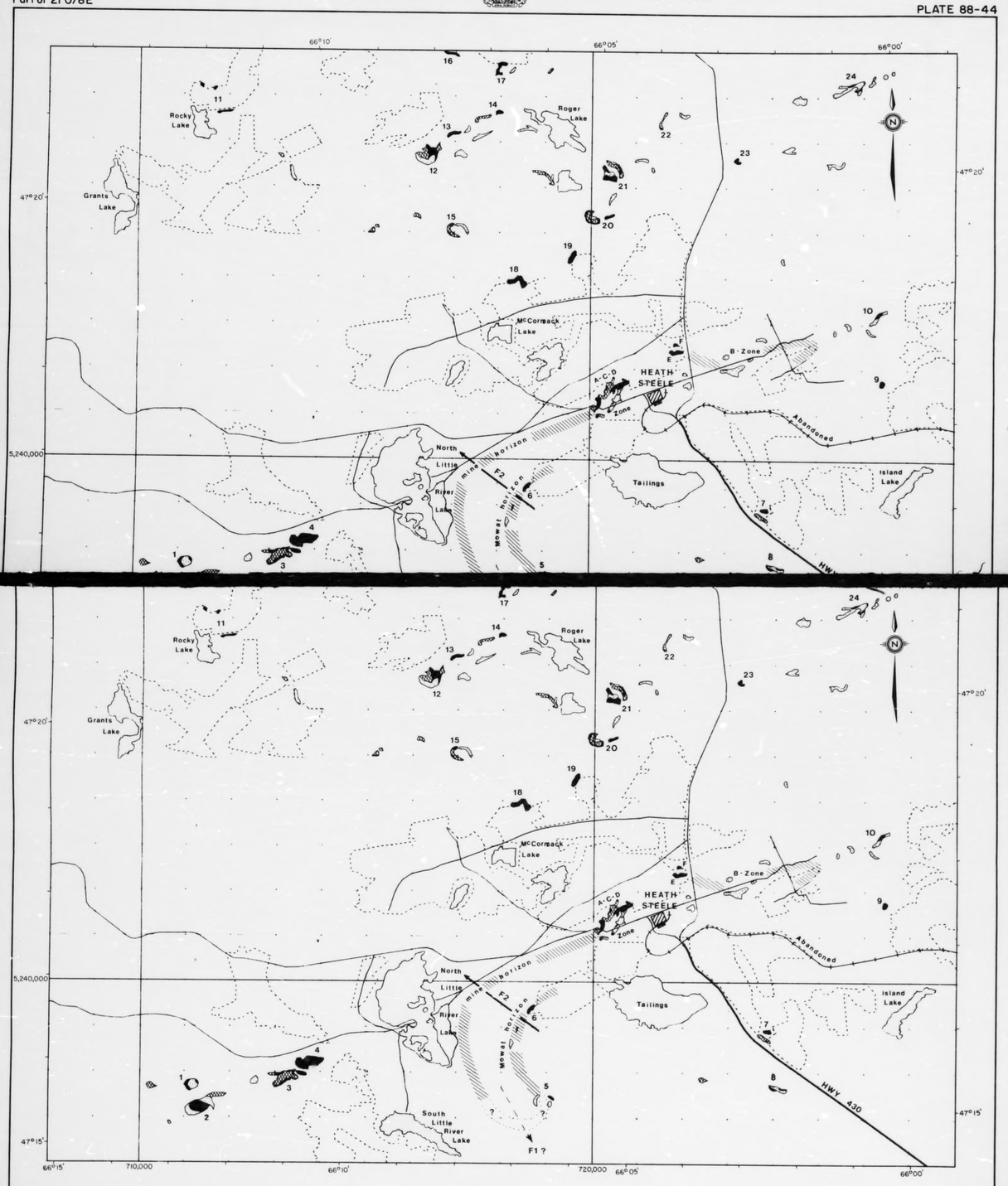
PLATE 88-44



HEATH STEELE MINE PROJECT: LAND USE/GOSSAN SIGNATURE SEARCH VECTOR MAP COMPILED FROM LANDSAT-4 THEMATIC MAPPER IMAGERY

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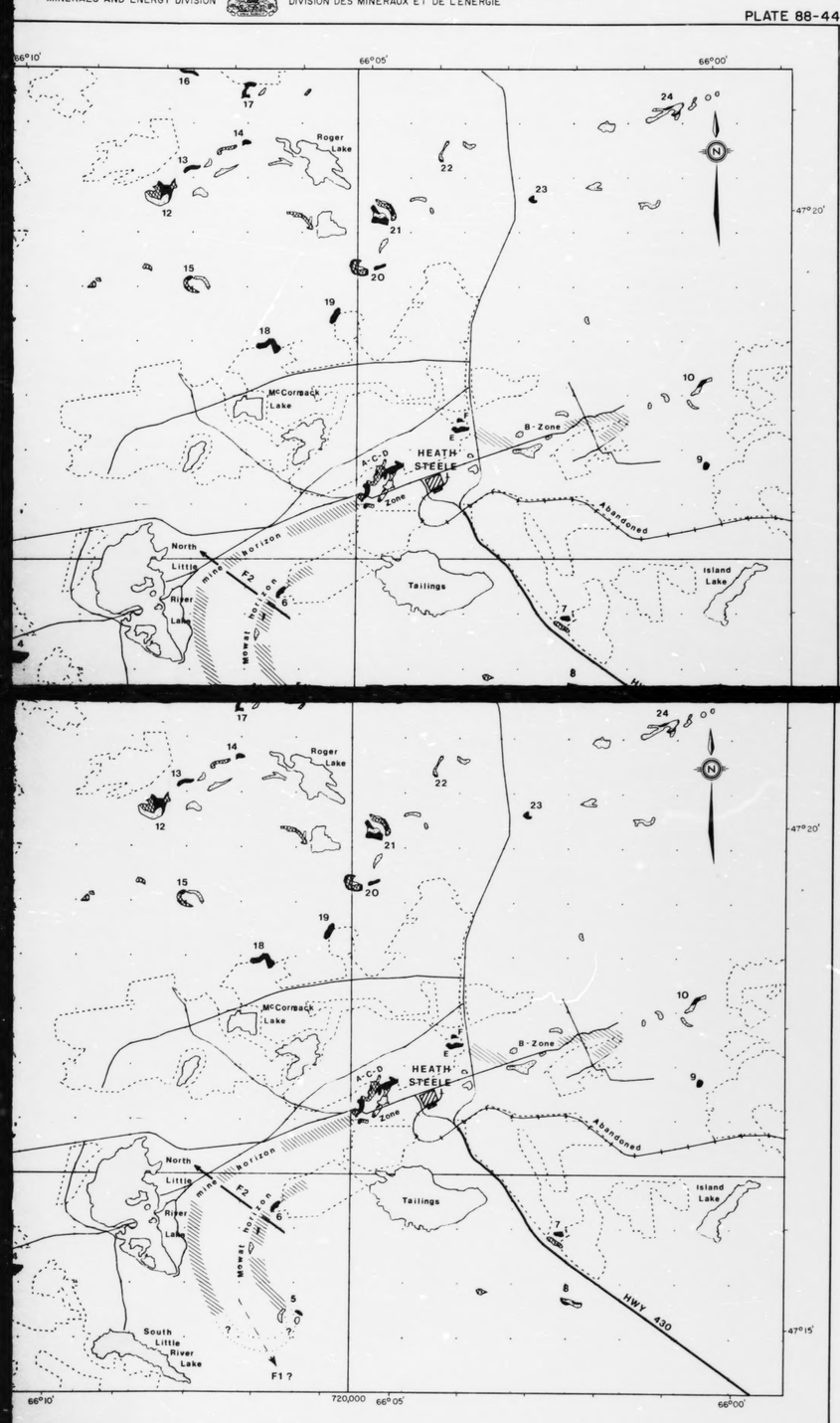
PLATE 88-44



LEGEND

- Lake, pond
- Gossan target (areal and discrete search)
- Gossan target (areal search)
- Gossan target (discrete search)
- Paved road
- Gravel road
- Railway line
- Clear-cut area

Projection: UTM Zone 19

Latitude/Longitude: Superimposed using GSC. National Topographic Series (21 O/8), 1957 edition.

Data Sources: LANDSAT-TM Bands 1-7, Sept. 1987.
GSC. Airborne Magnetic Survey 21147G.

Operators: M. Lodin, J.C. Torrance

Compilation: GEODAT Information Services Ltd.
301 Woodstock Rd., Fredericton, N.B.
E3B 2H9

Scale 1:50,000 Échelle

Miles 1 0 1 2 3 Miles

Metres 1000 0 1000 2000 3000 4000 Mètres

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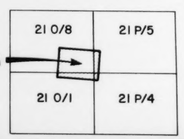
Ce projet fut financé en vertu de l'entente Canada-Nouveau-Brunswick sur l'exploration minérale, une entente auxiliaire de l'entente cadre sur le développement économique et régional.



To accompany
Open File Report 88-23

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